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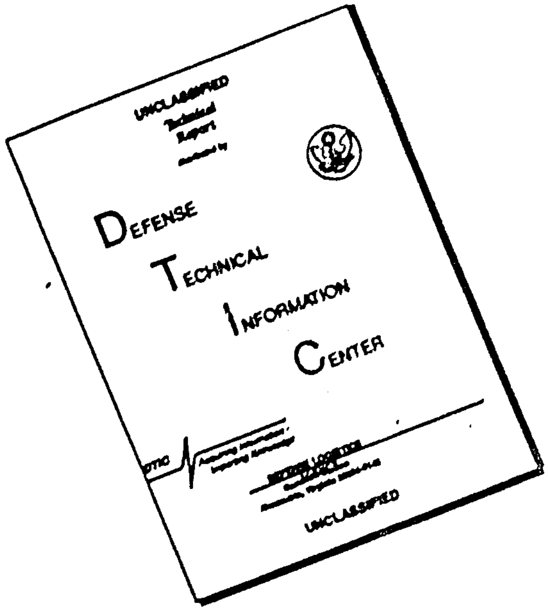

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DEVELOPMENTAL HISTORY OF AUXILIARY HEATING SYSTEMS FOR THE INDIVIDUAL COMBAT SOLDIER

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DEVELOPMENTAL HISTORY OF AUXILIARY HEATING FOR THE INDIVIDUAL COMBAT SOLDIER

1. Introduction.

Auxiliary heating is as basic a need for humans in their struggle for survival as food and clothing. Auxiliary heating has been a direct adjunct to shelter since prehistoric times.

The survival of the human race in the colder climates is conclusive proof of the feasibility of using external sources of heat to maintain comfort and thermal balance.

The history of our civilization shows that the basic human needs are fulfilled by the means at hand, often in a completely empirical fashion. With the advance of technology, devices which proved useful were improved and refined. Thus, the campfire became a central heating system and the hot water bottle (warming pan) became an electric blanket.

Our debt to the past, therefore, is that it showed the feasibility of the basic idea of utilizing externally applied heat to the human body.

A history of the development of auxiliary heating devices can also be useful in locating those problem areas for which efficient solutions have not yet been found.

In a sense, we have reached the end of the line. There are many ingenious devices to heat the hands, the feet, and even the whole body under certain specific conditions. Now, the need exists to find ways of utilizing external heat to help an individual survive under the most extreme environmental condition without imposing physical restriction

on him. Man, at last, is claiming his freedom from external restrictions even under the most adverse conditions of his oldest enemy, the weather.

It is the purpose of this report to review the development literature and analyze the feasibility of providing a practical, independent auxiliary heating system for soldiers with the knowledge existing at this time.

In the review of the available literature, the following facts have been noted:

(a) Auxiliary heating, per se, has proven feasible.

(b) Satisfactory heating devices have been developed before the developers knew all of the exact physical and physiological parameters—in other words, completely empirically.

(c) Many existing systems of heating individuals are, therefore, probably extremely inefficient and wasteful—yet, at present, economically acceptable.

(d) In view of the tremendous demand made on a mobile individual under extreme environmental conditions, only the most efficient system has a chance of proving successful.

(e) Knowledge of the physiology of rewarming and heating is one of the key factors in determining and developing the most efficient system. Technological knowledge in heat producing and distributing devices is the other key factor.

The usual line of development is from the easy to the difficult and from the simple to the complex. The analysis and summary presented in this report has therefore been organised on the following sections:

(a) Warming or rewarming the extremities.

(b) Warming or rewarming the whole individual.

(c) The problem of keeping the individual in continuous heat balance.

DEVELOPMENT HISTORY

1. Attempts to warm or rewarm the extremities.

The hands and feet of the individual exposed to extremely cold environments have always been the first areas to cause trouble. These areas may be designated as the weakest link of the system because they have a great deal of surface area and relative small volume. For example, the hands may lose up to 36 KcCal/hr. through 2 clo mitts in an ambient temp of -40°. 1/ Considerable effort has been expended to develop devices that will enable an individual to rewarm his extremities when necessary.

The oldest and most common way of rewarming the hands and feet is to expose them to a radiant heat source--such as a stove or fire. During World War II, the German Army attempted to reduce the amount of heat required for rewarming by providing chemical heating pads to be slipped into the pockets as a portable rewarming device. 2/ They also attempted to prevent further injuries to casualties by placing heating pads on the feet before wrapping casualties in blankets prior to evacuation.

Some of the Technical Services of the U. S. Army--Signal Corps, Ordnance, Corps of Engineers--because of their urgent requirements for high dexterity in the manipulation of tools and precision instruments, were the first to initiate action to develop hand heating devices.

In 1943, the Signal Corps Climatic Research Unit explored a method of warming the extremities by means of air warmed by the chest. While they reported the method to be successful, it is likely that the success reported was in large measure a result of the exercise involved in operating a hand-powered air pump. 3/ The paper describing this system and the experiments conducted during its development did not describe control experiments to indicate whether or not the exercise "per se" was sufficient to raise the metabolic rate to provide the additional warmth to the extremities. All during World War II the Army Air Force sponsored extensive development work in the field of heated handwear, footgear, and clothing for use by pilots. 4/ The availability of a power source led to the use of electricity. Since power was available, the Air Force concentrated on developing completely heated clothing rather than specific heating for the extremities. One of the more significant studies conducted in this period is the one conducted by the Industrial Hygiene Research Laboratory in 1944. 5/ This study investigated the feasibility of using unheated flight suits with heated boots and gloves. The Laboratory concluded that the combination was very effective in protecting subjects in cold chamber tests down to -50° F with 5 mph wind while using only one-third of the electrical energy which would be used in heating the whole man. While this report did not throw much light on the basic mechanism of overall heat balance and reheating, it did show that some benefits, at least subjective, can be obtained by preventing heat loss through the hands and feet.

In June, 1945, the Aero Med Lab reported that the addition of a 25-watt electrical heating system to the A-6A footgear assembly raised the effective clo value from 1.64 to 12. 14 clo. [6] One Clo QM footgear equipped with the same heating system raised the clo value to 5 clo. The more recent QM development of the rubber insulated boots, having clo values of 2.6 - 2.8 clo, have somewhat taken the edge off the urgency for protection of the feet. With minimal auxiliary heating, the insulation value of the insulated could probably be raised to an extremely effective level.

The hands, however, requiring dexterity for fine manipulative functions, could not be protected by heavy inert insulation, and the search for suitable auxiliary warming and rewarming devices continued.

The CMC, active on the problem of providing improved hand protection for the combat soldier, investigated an experimental tool warmer in 1943. This tool warmer showed some promise but had the same great disadvantage of requiring a source of abundant power.

In 1945, the QM Climatic Research Laboratory, delving into the problems of rewarming the hands suggested that because of the low conductivity of tissue, locally applied heat should be applied to the whole hand and wrist area, rather than just to the palm of the hand. In experiments with auxiliary hand heaters, it was noted that the skin temperatures of the back of the hands were consistently lower than the values for the thumb and middle finger.

The QM CRL concurrently investigated theories and design of heated suits. Working models of suits using parallel circuits of rubber tubing were designed as "steam-heated" garments. A small, lightweight boiler with a 2-way manifold was used for reheating and recirculation. The design limitations of such a system lie in the difficulty of achieving uniform coverage of the body with heating elements and the maintenance of adequate circulation in a flexible moving system.

In a report entitled, "THEORETICAL CONSIDERATIONS OF AUXILIARY HEATING AND EFFECT OF HEATER SPACING",[8/] Dr. Allan Woodcock calculated the extent of body area which must be covered in order to provide required amounts of heat to the body under various temperature conditions. In this work, a nomogram was constructed to show the variations. Part of the work done by Belding, at University of Pittsburgh under a contract with the U. S. Army QM R&E Command in 1957, [9/] corroborated Woodcock's figures on both the maximum amount of heat which can be put into the human body per unit area and the areas which must be covered in order to permit a given required heat input.

In February, 1949, QMC received a request from Office of Chief of Engineers to develop heated gloves and/or hand warming devices for certain types of Arctic operations, such as maintenance and sub-assembly work, surveying, and operation of precision instruments and steel tapes.[10/] On 5 April, a conference was held in OQMG with representatives of Signal Corps, Ordnance, and Corps of Engineers to define the common needs and establish

firm requirements. Draft MC's were subsequently written. These MC's were approved in 1950.[11]

As a result of an agreement made at the 5 April Conference, the QMC provided the Corps of Engineers with a test quantity of Catalytic Hand Warmers Ex-48-2. The Engineer R&D Laboratory concluded in 1950 that, while the handwarmers were not satisfactory, "the principle of handwarming is sound and that handwarmers are necessary for Arctic operations." [12], [13]

On the basis of studies conducted at QM CRL on overall heat balance, which strongly suggested that the problems of keeping the hands and feet warm were really peripheral problems, emphasis gradually shifted to investigations of how the total body could be kept warm or rewarmed.

2. Attempts to warm or rewarm the whole individual.

The realization that complete and efficient rewarming of the hands without also rewarming the body may not be possible[14], [15] provided a strong stimulus for reviewing the methods for rewarming the individual.

The oldest and most common method was and still is the use of a heated tent or a heated room. Campers, hunters, and even the present-day soldier are almost entirely dependent on this rather inconvenient means. The soldier, well protected when engaged in mild-to-moderate activity, becomes thoroughly chilled when remaining inactive in extremely cold environment for 1-1/2 to 2 hours. He then has to return to his "rewarming base." If he does not rewarm, he will most certainly become a casualty.

At this point, his clothing actually hinders him in the immediate goal because the mass and bulk of the cold weather uniform introduces a lag in the rewarming time.

A rule of thumb used by the U. S. Army in Alaska in measuring the combat effectiveness of men during the Arctic winter is that performance is reduced by 2 per cent for every degree below zero degrees F. This rule implies that at minus forty degrees F., the men are only about 20 per cent combat effective.

The present method of rewarming appears to be not only time consuming and inefficient, but a strong question can be raised as to whether any real reheating takes place.16/ Evidence presently available indicates that this method reduces the rate of heat loss and that any rewarming remains a physiological function. The efficiency of the mechanisms of rewarming must therefore be assessed.

During the Korean action, U. S. troops tried to reduce the need for rewarming and rewarming time by pinning Medical Corps chemical heating pads into the clothing of men with inactive occupations, viz., guard duty, listening posts, etc. These attempts met with a small degree of success although it is difficult to determine to what extent psychological factors played a role.

Experiments conducted by QM REA in 1954 to verify the above-mentioned results confirmed that, in principle, heat pads can be used to <u>extend</u> the tolerance time. However, the existing pads were considered entirely impractical from a standpoint of weight, bulk, duration, and stability of heat produced.17/

The chemical heating pads were designed for use as a therapeutic device and have also been used in casualty evacuation. In view of the present casualty evacuation methods and the known elapsed times between becoming a casualty[18] and arrival in the field hospital, it is clear that these pads are very ineffective and only a stop-gap measure, at best.

Consequently, emphasis shifted to the development of casualty evacuation devices which would more effectively rewarm the body or, at least, prevent further heat loss. The following approaches were taken: The QMC designed a special casualty evacuation bag having greatly increased insulation value. This approach did not use auxiliary heat but attempted to allow the casualty to rewarm himself by preventing further excessive heat losses.

The other approaches were developed under contract and utilized auxiliary heat. The first was developed by the Wyandotte Chemicals Corp. in 1953. [19] It consisted of a gas turbine power pack and a blower to transfer heat of combustion to heat the transfer fluid.

The other approach, developed by Jet-Heet [20] also in 1953, utilized a propane gas burner to heat an alcohol mixture which was circulated by a pulsating pump system.

Both approaches demonstrated that a portable heating device is feasible (with certain practical limitations). The physiological effectiveness of these approaches again could not be assessed simply because not enough was known about the physiological parameters of rewarming.

To obtain the much-needed information on the bio-physics and physiology of rewarming, a contract was awarded to the University of Pittsburgh.[9] The contractor reported in 1955 on his findings on "Bodily Acceptance of Locally Applied Heat." This study was a very important step in properly evaluating many earlier, empirical findings. The most important finding was that, while heat can be put into the human body, the amounts are relatively small. In the search for the most efficient system for use by the individual combat soldier, it suggested very strongly that, rather than attempting to rewarm an individual, auxiliary heat should be applied to prevent the individual from losing excess heat in the first place.

3. Auxiliary heating devices to keep the individual in heat balance.

The existing methods of rewarming being considered time consuming and inefficient, military clothing design then focused attention on the problem of developing clothing and auxiliary heating devices that enable an inactive man to remain in thermal balance.

The U. S. Air Force has so far been the only military user who has found an effective solution to this problem for one category of their personnel: those whose occupations place them near a power source. The Air Force solution has been the electrically heated suit, gloves, and boots.

The development work on electrically heated suits for the Air Force, during World War II, was not, to any great extent, hampered by the lack of

precise physiological criteria since power was not particularly critical. The main concern, however, was what would happen if the power source failed. In the development of the electrically heated clothing, the designers used the pilots' comfort as the main criterion.

In a memorandum report on Electrically Heated Flying Clothing, dated 22 April 1943, the Harvard Fatigue Laboratory reported, after observing performance of the suits at temperatures down to -60°F: "Nowhere has man existed for 8 hours, inactive, exposed to these temperatures, without heated clothing." 21/ Similar reports have been published by the National Institute of Health. 22/ 23/

Several years later, in 1948, the Air Force decided to evaluate heated clothing for use by aircraft mechanics. 24/ These studies were conducted at Ladd AFB. The conclusion was that the use of electrically heated clothing by mechanics exposed to severe cold, with the provision of a portable power plant, is highly desirable and acceptable.

QM CRL, following these Air Force developments, evaluated the electrically heated clothing at Ft. Churchill and also found that comfort and heat balance could be maintained. These results were obtained, of course, at the expense of restricted mobility: the subjects had to remain within the range allowed by the cord supplying power to their suits.

However, in 1955, electrically heated ensembles were evaluated for use by Skysweeper personnel Alaska. 25/ ATB reported that the

clothing did not prevent the men from becoming chilled. This adverse report is probably due to the fact that not enough outside insulation was provided over the electrically heated clothing.

The Air Force, due to the need for anti-G and pressure clothing, has explored other means of keeping the man in thermal balance. The most promising method was the use of warm air being introduced between the body and the outer clothing. Their findings were summarized in 1949 in: "The Biophysical Requirements for Ventilated Clothing." 26/ This important report summarized the requirements to that date and served as a basis for design of ventilating clothing where a power source is available. Auxiliary heating systems for the infantry soldier still required more losses and the feasibility of body rewarming.

In 1955, a QM contract was awarded to the University of Pittsburgh in an attempt to fill the gap in the knowledge of the physiology of thermal balance. Belding's work in outlining the portions of body area which can accept given levels of heat is considered a major step forward. One of the specific recommendations resulting from his work is that the maintenance of thermal balance is more efficient than known methods of rewarming.

With the growing awareness of the feasibility of maintaining thermal balance, studies were initiated on the design requirements for a completely enclosed all-environment clothing system. A QM contract was awarded in 1956 to State U. of Iowa to study the physiological, psychological, and biophysical implications of such an approach. 27/ This report confirmed the

basic feasibility but pointed out many unresolved problem areas. It stressed that the heat distribution system is extremely important.

In 1957, the QM advanced the concept of a "thermalibrium" ensemble, and ensemble consisting of an insulating layer, a distribution system, and a two-way heat pump. 28/

Development of a suitable hot air distribution system has progressed slowly because of the requirement for very low back pressure in the system. The power limitations of portable air moving and heating devices simply prohibited the utilization of existing air distribution devices.

The U. S. Air Force, not having the low back pressure requirement, developed the Mauch ventilating garment. A considerable amount of work in this area has also been done by the RAF Institute of Aviation Medicine. A report was published in March 1953 on the RAF ventilated suit. 29/ This garment required 6 psi in order to deliver 168 liders per minute.

In 1958 the QMC fabricated a simple air distribution device to be incorporated in a liquid air-cooled rocket fuel handler's ensemble. This device proved to have extremely low back pressures at low to high flow rates. It could easily be incorporated in other types of clothing.

The air distribution device consisted of a plenum chamber, having facilities for connecting to an air supply source, and four flexible hoses leading air to the extremities. The air was released near the hands and feet and allowed to flow underneath the clothing to various natural exit points.

Cold chamber experiments, utilizing the low pressure air distribution approach, were conducted to determine how well body heat could be maintained by supplying hot air. [30]

The major finding of these experiments was that, in order to extend the tolerance time of inactive subjects in extreme cold, heat must reach the extremities so as to prevent the hands and feet from becoming cold while the body itself is in positive heat balance.

It also became apparent that the experimental QM air distribution device did not fulfill the functional requirements for such a unit. One important shortcoming was the fact that too much heat was given off to the body before the air reached the extremities.

Work on the thermalibrium approach is presently continuing along the following lines:

(a) The development of a heat regulation device.

(b) Research on methods and techniques to distribute available heat in order to establish a psychologically acceptable micro climate.

THE DEVELOPMENT OF AN AUXILIARY HEATING SYSTEM TO EXTEND THE TOLERANCE TIME IN EXTREME COLD WEATHER

In 1959 the committee on Hand functioning and Handwear, NRC, which had been formed to advise the QM, made the recommendation that the general question of applying auxiliary heat within insulated clothing be studied in terms of the feasibility of increasing cold tolerance by auxiliary heating at reasonable power weight levels. [31] [32]

The available data suggested that a practical method of greatly extending the tolerance time of inactive men exposed to extremely cold environments could be developed since initial studies [33] indicated that:

1. The insulation provided to the body torso by the standard QM clothing is not the limiting factor in reduced tolerance time to cold environments. In other words, little or no auxiliary heat is needed in this area.

2. Auxiliary heat supplied only to the extremities will extend tolerance.

3. It is not necessary to maintain the extremities at 80°F levels.[34] [35]

A series of cold chamber experiments were conducted to measure electrical power requirements to achieve 8 hours tolerance in extreme cold conditions. The tests were conducted at -40°F with a 10 mph wind.[36] Subjects remained inactive and wore the standard arctic mittens over knitted wool/resistance wire gloves. The standard cold-dry white boots were worn over knitted wool/wire socks. The complete arctic ensemble was utilized.

By varying the wattage during these experiments, determinations were made of the power required to maintain the foot at different temperatures. Approximately five (5) watts per foot maintain minimum foot temperatures at +60°F. Fifteen (15) watts are needed to maintain 2 hours of protection before auxiliary heat is needed.

Temperatures of the little finger can be maintained at +60°F with 5 watts per hand. The standard arctic mittens provide approximately two (2) hours of protection before auxiliary heat is needed. Thus, in order to meet the requirement for 8 hours of protection, a total of about

140 watt hours to the hands and feet are needed to <u>maintain</u> a minimum temperature of 60°F. However, 5 watts is inadequate to rewarm a hand or foot cooled appreciably below 60°F skin temperature. 10 watts will be more than adequate for rewarming.

The choice of the minimum temperatures to be maintained was influenced by several factors. Effective dexterity and comfort start to drop off rapidly when skin temperatures fall below 55°F.[37/38] Maintaining the skin temperatures at 80°F would greatly increase the power requirements. Sixty degrees F was selected to provide a safety margin of 5°F over the 55° minimum, especially since it was realized that the hands will at times be removed from the mittens.

Essential requirements to translate the above mentioned findings into a practical auxiliary heating system were the availability of a lightweight, portable power source and suitable thermostats that could be incorporated into the handwear and footwear.

A review of commercially available power sources indicated that a rechargeable power pack, weighing approximately 6 or 7 pounds could be developed to provide 120 watt hours. Since the period of inactivity will seldom exceed four (4) hours during the usual 0 to 10 hour duty cycle, this power source should maintain the finger and toe skin temperatures at a minimum of 60°F <u>if</u> reliable temperature controls could be incorporated, within the handwear and footwear, to eliminate power drain when no heat is needed.

Available theromostats are still considered too bulky for comfort when worn against the fingers. As a result of a detailed experiment, a location has been selected which will allow the use of available thermostats; that is, the dorsal fleshy web between the thumb and the hand. While thermostating the knitted socks could not be achieved without wearer discomfort, it was found that the power required to heat an insulated boot was not excessively greater than that to heat the socks. The boots could be thermostated under the area of the fifth toe without discomfort.

In order to eliminate hot or cold spots, an even power distribution must be obtained. Electrical resistance wires incorporated into a knitted glove lend themselves very well for this purpose. However, the very nature of knitted construction allows tremendous heat loss when the hand and auxiliary heated glove is removed from the mittens and is exposed. A wind proof layer is considered essential.

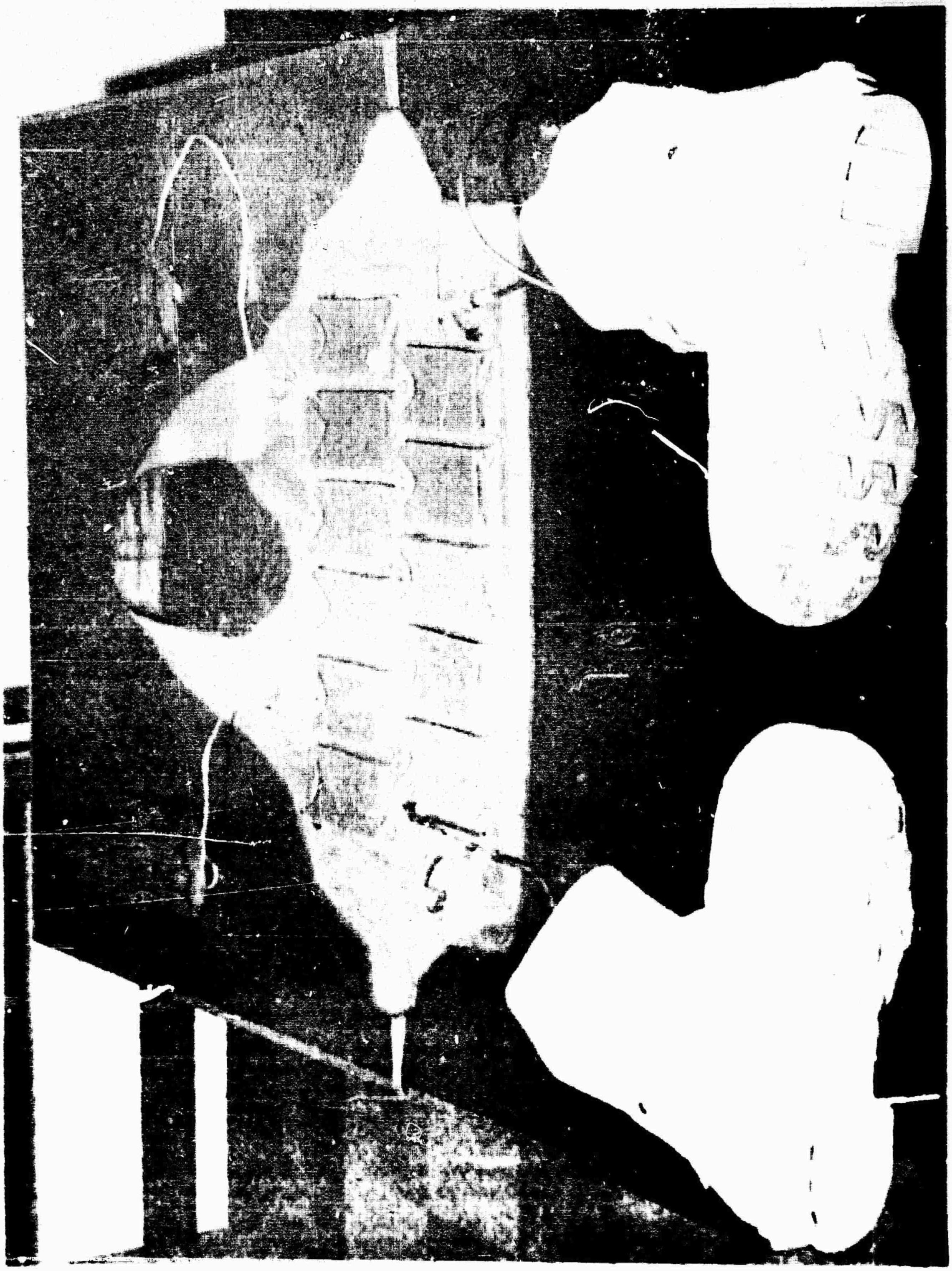
Finally, a complete auxiliary heating kit, based on the best available information was contructed. This kit, (figure 1), consists of the following items:

1. Gloves, Auxiliary Heating, knitted with wool and wire, Thermostatically controlled.

2. Vest, Auxiliary Heating, (121 volts, 11 silver cadmium batteries, 120 watt hours capacity).

3. Boots, Auxiliary Heating, Cold-Dry, Insulated, Thermostatically controlled.

A special recharging unit, required for the Battery Vest, is available in a single or triple unit. This kit, when worn with standard QM clothing, will allow the soldier to remain effective, even while inactive, when exposed to extreme cold-dry conditions for periods of up to 8 hours. The entire system is now ready for field evaluation.



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